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A REVIEW OF THE USE OF RECOMPRESSION DEVICES AS A TOOL FOR REDUCING THE EFFECTS OF BAROTRAUMA ON ROCKFISHES IN BRITISH COLUMBIA

Context

Pacific Rockfish (genus *Sebastes*) suffer high rates of barotrauma when they are brought to the ocean's surface because they have a closed, or physoclistic, gas bladder. Although many jurisdictions recommend the use of descending devices that return recreationally caught fish with barotrauma to depth, little research on the use of these devices and the survival of recompressed fishes has been done in British Columbia.

Fisheries Management has requested advice from Science to inform decisions about management strategies for the recreational fishery that will achieve rockfish mortality reductions. It is expected that advice will be compliant with both the "*DFO Sustainable Fisheries Framework*" (SFF) policy and "*A fishery decision-making framework incorporating the Precautionary Approach*" (PA) policy.

Objectives

The Science Response will be used to provide advice with respect to the following objectives:

1. Review the state of knowledge regarding the effects of barotrauma on rockfishes and the ability of recompression devices to decrease mortality of released fish in the short- and long-term.
2. Document types of descending devices and what is known about each.
3. Synthesize study results for each species that occurs in BC.
4. Provide advice regarding research gaps and uncertainty.

This Science Response Report results from the Science Response Process of June 2018 on a review of the use of recompression devices as a tool for reducing the effects of barotrauma on rockfishes in British Columbia.

Background

Rockfish (genus *Sebastes*) are a species-rich group, with over 102 species found globally and at least 38 in the coastal oceans of British Columbia (BC). These species all share common life history traits, physiology, and general morphological characteristics (Love et al. 2002). Fisheries and Oceans Canada has grouped rockfish into 3 categories based on depth distribution along the coast. Slope species (15 species) are generally found in deep water (100-2000 m) and are most abundant in the upper regions of the continental shelf. Shelf species (15 species) are found at depths ranging from 0-600 m and are predominantly found near the edge of the continental shelf. Inshore species (8 species) are most numerous at shallow depths (0-200 m) in rocky areas with high-relief bottoms. These inshore rockfish species are subject to commercial, recreational, and First Nation fisheries, while the shelf and slope rockfishes are targeted by commercial trawl and hook and line fisheries.

BC's inshore rockfish species (Yelloweye, Copper, Tiger, China, Quillback, Black, Deacon (formerly Blue (Frable et al. 2015) and Brown rockfishes) are, like other rockfish species, long-lived (some have lifespans exceeding 100 years), late maturing, have small home ranges, and demonstrate high site fidelity. Rockfish are viviparous, with the largest and oldest females making significant contributions to the populations by giving birth to over one million larvae in a single breeding season (Love et al. 2002). Most bony fishes have a hydrostatic organ called a gas bladder that is used for buoyancy control and, in some cases, sound production. Unlike some fish species, the swim bladder in rockfishes does not have any connection to the stomach, meaning the release or uptake of air occurs by diffusion into (to release) or out of (to uptake) the bloodstream through a specialized network of blood vessels called the *rete mirabile*. The rate of gas removal is therefore dependent on the rate of blood flow and is not instantaneous (Parker et al. 2006). Fish with a closed gas bladder are called "physoclists". These reproductive, life history, and physiological characteristics make inshore rockfish susceptible to the impacts of even moderate levels of localized fishing, and associated declines in populations may take decades to reverse.

Rockfish populations along the west coast of North America, including British Columbia, have suffered dramatic population declines since the advent of industrial fishing methods (Parker et al. 2000, Yamanaka and Logan 2010). In 2002, Fisheries and Oceans Canada announced a strategy to conserve inshore rockfishes, which included measures to account for all catch including bycatch and discards, decrease fishing mortality, establish areas closed to all fishing, and improve stock assessment and monitoring (Yamanaka and Logan 2010). Accounting for bycatch and discards and the use of closed areas were important aspects of the conservation strategy because discarded rockfish suffer high mortality associated with decompression effects related to their physiological inability to rapidly vent gas from their swim bladder, as noted above.

The volume of a gas will increase as pressure decreases; thus when a physoclist is quickly brought to the surface from depth, their swim bladder enlarges and they experience barotrauma. The change in swim bladder volume is greater in shallow water than the change in volume that occurs when making the same absolute change in depth in deeper water. This creates a narrow zone of neutral buoyancy in shallow waters that results in constraints on a fish's natural vertical movements. It also results in injuries associated with forced decompressions as a fish is brought to the surface during fishing, even when fishing in relatively shallow water (Parker et al. 2006).

In addition to the physiological barotrauma effects which are discussed below, rockfish brought up to the surface and discarded will be "floaters," as they are often unable to return to depth, and are at risk of predation from birds and mammals while at the surface (Hannah et al. 2008a). As a result, catch-and-release is not an appropriate management tool for rockfishes. Groundfish fisheries managers consider mortality of released rockfish from recreational and commercial fisheries to be 100%; however, the release of rockfishes is prohibited as a condition of license in the commercial fishery and is enforced by electronic or onboard monitoring and audit programs (DFO 2017). Mortality of discarded fish and sub-lethal effects of barotrauma on rockfishes must be considered in management measures, such as the use of Rockfish Conservation Areas (RCAs), other closure zones, and accounting for all catch including bycatch and discards (Yamanaka and Logan 2010). Mortality of releases has also lead to the "Keep What You Catch" guideline, whereby anglers are required to retain rockfish regardless of their size until the daily limit is reached, and to move fishing spots to avoid rockfish rather releasing them.

The use of recompression devices (Theberge and Parker 2006, Chen 2012) that return rockfish from the surface to their capture depth is currently being explored for inshore BC waters as a mitigation method to reduce mortality of released rockfishes. Descending devices are recommended for use by recreational fishers in many US jurisdictions (Benaka et al. 2014) and

have recently become required in some jurisdictions (Washington and Oregon). Descending devices are commercially available and can also be homemade. Numerous studies have been performed to assess the effectiveness of recompressing different rockfish species (Parker et al. 2006, Hannah and Matteson 2007, Jarvis and Lowe 2008, Hochhalter and Reed 2011, Pribyl et al. 2011, Hannah et al. 2014, Rankin et al. 2017). Most of these studies have focused on immediate post-release mortality, but a few have examined longer-term, sub-lethal impacts on individual fish.

To conduct this review, a literature search was conducted, and information presented at the "Rockfish Recompression Workshop" on October 28th, 2016 at the SFU Wosk Centre for Dialogue, Vancouver BC, was reviewed. Information presented at the Western Groundfish Conference's session on the use of descending devices on February 13, [illegible]8 also informed this work.

A limitation in the literature is that little research on the effects of barotrauma and the use of recompression has taken place in BC, resulting in the need to extrapolate from research elsewhere; primarily from research conducted in the United States. Some of the research on barotrauma in rockfishes has been conducted in California and is, therefore, focused on southern species that are not found in BC; however, research conducted in Oregon, Washington and Alaska is more pertinent to rockfish species in BC.

Analysis and Response

Studies on Rockfish Barotrauma and Recompression

The effects of barotrauma and recompression on rockfish that have been brought to the surface have been studied in both laboratory and field settings (Parker et al. 2006, Hannah and Matteson 2007, Jarvis and Lowe 2008, Pribyl et al. 2011, Hannah et al. 2012, Pribyl et al. 2012). These studies range from studies of immediately evident internal injuries from barotrauma and recompression, to *in situ* observation of behavior at depth after barotrauma and recompression, to observation of behavior and ability of fish that have been decompressed to descend when released at the surface. A few studies catch, tag, and release fish so that long-term survival after recompression can be studied (Hochhalter and Reed 2011, Wegner et al. 2016).

Depth of Capture, Variability among Species and Other Sources of Variability Affecting Survival

The severity of barotrauma experienced by a rockfish due to forced decompression by fishing is influenced by a number of correlated factors, as is how the fish responds to the barotrauma and what its chance of survival is with and without being returned to depth. The absolute change in pressure/depth that the fish experience determines the volume change that the fish's swim bladder will experience. Internal injuries including cardiac injury, hematomas, swim bladder and pericardium ruptures, liver hemorrhages, and digestive system injuries showed clear patterns of increased severity as the pressure increased in a laboratory study of decompression on Gulf of Mexico Snapper (*Lutjanus campechanus*) (Rummer and Bennett 2005). The depth of capture has also been found to significantly affect the severity of barotrauma as well as the fish's subsequent behaviour and survival in rockfishes (Hannah and Matteson 2007, Pribyl et al. 2011, Hannah et al. 2012, 2014); however, depth is not always found to be a significant variable (Jarvis and Lowe 2008, Hochhalter and Reed 2011). The influence of the depth of capture on barotrauma and survival is complicated by the depth selectivity of the numerous rockfish species, their behaviour and anatomy, as well as the confounding effect of temperature change that co-occurs with a change in pressure and depth. Pribyl et al. (2011) reported a significant role of capture depth on the presence or absence of macroscopic signs of barotrauma in

Quillback and Yelloweye Rockfishes. Similar results have been reported by Jarvis and Lowe (2008) whereby increasing depths of capture lead to increasing signs of barotrauma. However, these researchers found that depth was only a partial predictor of initial post-decompression survival. Differences among species is often a better predictor of survival than depth, due to the variability of swim bladder morphology and other species-specific adaptations related to their life history strategies (Hannah et al. 2008a, Jarvis and Lowe 2008, Pribyl et al. 2011).

The numerous species of rockfishes in the genus *Sebastes* have been described in terms of a species flock (Alesandrini and Bernardi 1999, Hyde and Vetter 2007). Rockfish speciation likely occurred along a depth gradient (Ingram 2011). Ingram (2011) showed that there was a strong signal of speciation in the depth habitats and traits that adapt species to different depths, such as the size of the eyes, an adaptation to low light levels. Morphological differences in swim bladder traits such as bladder shape and membrane thickness, and variations in body cavity space available for swim bladder expansion have also been noted for different species; this may result in species-specific differences in barotrauma (Jarvis and Lowe 2008, Rummer and Bennett 2005).

Life history will also affect how different species are adapted to pressure changes. Rockfish species that have adapted to vertical movements up and down the pressure gradient have faster gas secretion and resorption capabilities. For example, Black Rockfish are semi-pelagic, and known to move vertically as aggregates/schools within the water column. China rockfish, by contrast, tend to be more solitary, and live in rocky crevices on the bottom. Black rockfish have a much larger, more developed *rete mirabile* – specialized network of connected blood vessels – and higher red blood cell content than demersal China Rockfish, which enables faster gas transfer rates in the swim bladder as depth frequently and rapidly changes (Parker et al. 2006). Parker et al. (2006) also found significant differences between the species after exposure to pressures equivalent to depths of 30 m in an experimental hyperbaric chamber, with Black Rockfish acclimating (i.e., to be neutrally buoyant) in 48 hours, and China Rockfish needing over 250 hours to acclimate. In order for semi-pelagic fishes, such as Black and Blue Rockfishes to make greater vertical movements (Table 1), they need to be neutrally buoyant at a depth much shallower than their mean depth. Because capture depth may be closer to neutral buoyancy depth for demersal species, it is thought that semi-pelagic individuals captured at the same depth should show less barotrauma than a demersal species (Parker et al. 2006).

Yellowtail Rockfish, a pelagic species that makes large vertical movements, show low rates of barotrauma and gas bubbles have been observed emanating from under their opercula during ascent (Hannah et al. 2008b, Pribyl et al. 2009). Pribyl et al. (2009) used decompression chambers to simulate decompression from a depth of 35 m and found that when comparing Black, Blue, and Yellowtail Rockfishes, the Yellowtail Rockfish were less likely to suffer from both macroscopic and histopathological injuries. Yellowtail rockfish did not show any external signs of barotrauma except the presence of gas bubbles in the pharyngo-cleithral membrane near the gills. Yellowtail rockfish release gas during decompression from the swim bladder via this membrane, so the reduced amount of gas in the swim bladder does not build up enough pressure during decompression to evert the esophagus or cause exophthalmia. Assumptions about how a species handles barotrauma are not always straightforward. For example, Quillback Rockfish is a species with a deep body, and exhibits a demersal behaviour with low levels of horizontal and vertical movement, potentially suggesting a limited ability to withstand pressure changes; however the opposite has been observed (Hannah et al. 2008b, Pribyl et al. 2011).

It is critical to consider the interaction of morphological and physiological attributes when reviewing the literature on this topic. Differences among rockfish species survival from barotrauma exist due to their evolutionary history and phylogeny, their physiological capacity to

respond to forced decompression, morphological differences, and life history patterns (Parker et al. 2006, Pribyl et al. 2011). The differences in rockfish species' life history, niche, habitats, movements, and depth preferences for the inshore rockfish and some shelf rockfishes are summarized in Table 1 so that barotrauma effects can be viewed with these characteristics in mind.

*Table 1. Life History characteristics of inshore and nearshore shelf rockfishes in BC. Group (G): In=Inshore, Sh=Shelf. Subgenus (SG): a= Sebastosomus, b= Pteropodus, c= Sebastichthys, d= Sebastopyr, e= Rosicola, f= Hispaniscus, g=Acutomenthum, h=Sebastodes. Niche: MW=Mid-water, B=Benthic. Movement: Horizontal (H), Vertical (V): H=High, M=Medium, L=Low, U=Unknown. *Juveniles are found in shallower water. (Richards 1986, Matthews 1990, Love et al. 2002, Hyde and Vetter 2007, Hannah and Rankin 2011).*

G	SG	Species	Depth Range (m)	Typical Depth (m)	Niche	Habitat	Max Size (cm)	Max Age	Move-ment H/V
In	a	Black (*S. melanops*)	0-366	0-100	MW	Kelp, high and low relief reefs, high current	69	50	M/M
In	a	Blue/ Deacon (*S. mystinus/ S. diaconus*)	0-549	0-90	MW	Kelp, high relief, exposed reefs	53	44	M/M
Sh	a	Yellowtail (*S. flavidus*)	0-549	90-180*	MW	High relief and sheer rock walls	66	64	H/H
In	b	Copper (*S. caurinus*)	0-183	0-90	B	Kelp, boulder fields and high and low relief reef	66	50	M/M
In	b	Quillback (*S. maliger*)	0-274	0-150	B	Kelp, boulder fields and high and low relief reef, sponges	61	95	L/L
In	b	China (*S. nebulosus*)	3-128	10-100	B	High relief rock with high current	45	79	L/L
In	b	Brown (*S. auriculatus*)	0-135	0-120	B	High and low relief reefs, sand	56	34	L/L
In	c	Tiger (*S. nigrocinctus*)	18-298	50-200	B	High-relief, high complexity reef	61	116	L/L
In	d	Yelloweye (*S. ruberrimus*)	15-549	50-200*	B	High-relief, high complexity reef	91	118	L/L
Sh	e	Vermillion (*S. miniatus*)	6-436	50-300	B	High relief rocks	76	60	L/L
Sh	e	Canary (*S. pinniger*)	0-838	100-200*	B	Pinnacles, high, exposed rock	76	84	H/H
Sh	f	Greenstriped (*S. elongatus*)	12-495	100-250	B	Boulders, cobble, rock rubble, mud	43	54	U/U
Sh	g	Widow (*S. entomelas*)	24-549	140-210	MW	School over rock outcrops, boulders and high relief.	59	60	U/H
Sh	h	Bocaccio (*S. paucispinis*)	122-478	50-250	B/MW	High relief rocks, boulders, mud	91	50+	H/H

Data on the depth range that rockfish species are caught at in recreational fisheries in BC is not available because capture depth is not recorded in the creel survey. Fishery-independent

surveys that use recreational hook and line equipment (Richards and Cass 1985, Haggarty and King 2006a, b, Frid et al. 2016) can be used to inform the possible capture depth of rockfishes. However, these surveys target certain depth ranges and may not cover the same depth ranges that are recreationally fished. The gear used in the survey also may not be representative of catches by recreational trolling or while targeting Pacific Halibut. The depth of capture of rockfish species from hook and line surveys does, however, show the differences in capture depth by species. Black, Copper, China, and Vermillion Rockfishes were typically caught above 30 m. Most Quillback and Tiger Rockfishes were captured at mid-depths between 30 to 50 m and most Canary, Yelloweye and Yellowtail Rockfishes were caught below 50 m (Figure 1).

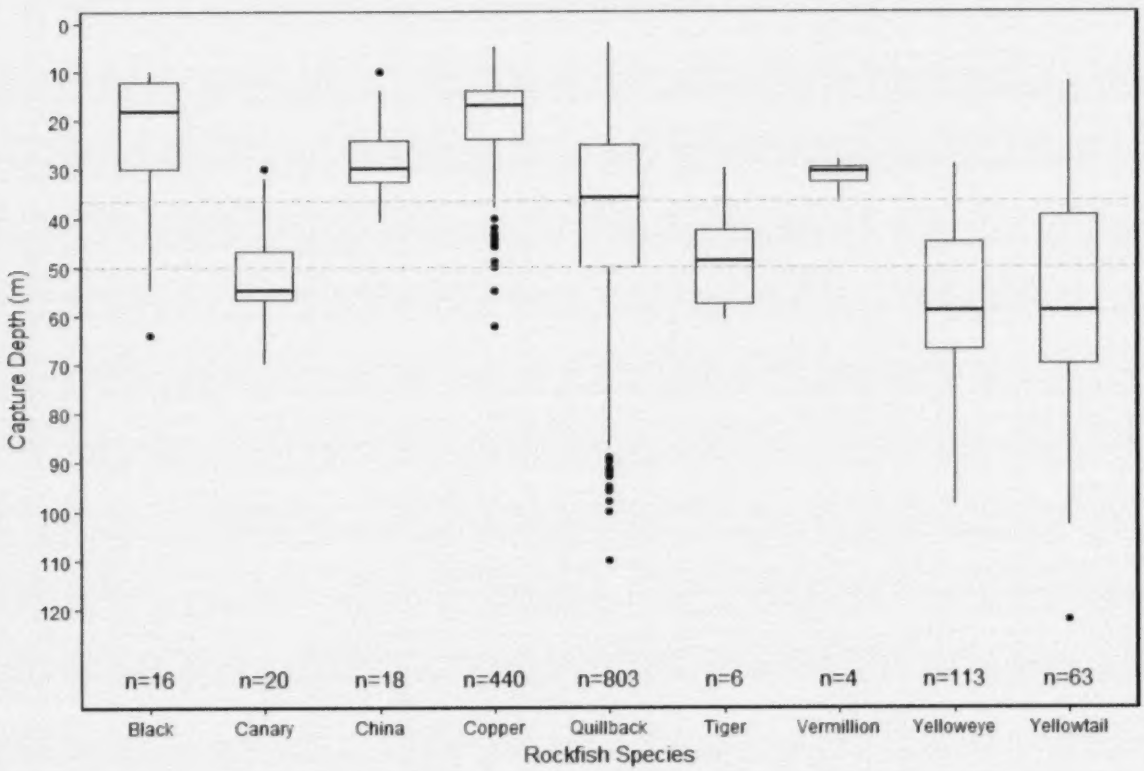

Figure 1. Boxplot of the capture depth of rockfish species on fishery-independent research surveys (data in GFBio and Frid et al. 2016). Dashed lines are shown at 36 and 50 m. The horizontal line in each box is the median depth and the hinges of the boxes are the 25th and 75th percentile. The whiskers or vertical lines are 1.5 times the interquartile range while the points are outliers that are plotted individually.

Temperature differences are also correlated with depth and the temperature change between the depth of capture and the surface can affect the severity of barotrauma in rockfishes (Pribyl et al 2011). Fish held at the surface or on deck are subject to heat stress, or cold stress, which can be a major cause of mortality (Parker et al. 2003). The temperature differential as well as the handling time significantly affected survival of rockfish species in California (Jarvis and Lowe 2008). Most studies examining specific effects of barotrauma handle fish carefully and keep the time on deck to a minimum. Other sources of variability include hooking and handling injuries and capture stress. However, all of the studies reviewed took care to minimize and control for these physiological (i.e. susceptibility to pressure effects) and physical (i.e. capture-related with

respect to depth, temperature and handling) effects. The size and sex of the fish may also affect survival post-release. Smaller fish may be more susceptible to barotrauma due to smaller blood vessels that are more sensitive to large gas bubbles (Jarvis and Lowe 2008) and smaller fish may suffer greater predation rates. Differences between sexes may also contribute to the severity of rockfish responses to barotrauma; however this is likely only when highly gravid females are subjected to forced decompression. Gonad volume did not seem to have a significant impact on recovery of Yelloweye Rockfish and evidence on evidence of successful breeding in female Yelloweye Rockfish has been found (Blain and Sutton 2016).

The Physical Effects of Barotrauma in Rockfish (Sebastes) and Survival after Recompression

When a rockfish is brought to the surface, gas contained in their closed gas bladder expands. Discarded rockfish are so positively buoyant that they float on the surface, and often succumb to predation and/or thermal stress (Hannah et al. 2008a). Predation is likely the most immediate and obvious cause of post-release mortality in rockfish suffering from barotrauma. However, there are other short- and long-term effects of barotrauma. As the gas in the swim bladder expands, it follows the path of least resistance in the fish, which is usually in an anterior, or forward, direction in rockfishes (Hannah et al. 2008b).The most visible signs of barotrauma in rockfishes include bulging eyes, "pop eyes" (exophthalmia) and a protruding esophagus (esophageal eversion). The protruding esophagus is often thought to be the swim bladder; however, as the expanding gas moves forward it causes the esophagus and sometimes stomach to "roll out" (Hannah et al. 2008b). The gas that leaks out of a ruptured gas bladder also moves forward and can collect within the orbits leading to exophthalmia. As the eye is pushed out of the head, the optic nerves are stretched. Gas bubbles may also collect in the eyeball or cornea, or connective tissue of the eye (Hannah et al. 2008b, Rogers et al. 2008). Sublethal visual damage due to barotrauma includes impaired vision which may lead to increased susceptibility to predation, and decreased ability to find forage. Both of these behavioral impairments have implications for the long-term survival of rockfish that have suffered from barotrauma. Although little research has been done on the visual acuity of rockfish following exophthalmia, one study on Rosy Rockfish (*S. rosaceus*) showed improvements in eye function one month, as compared to 4 days, after exopthalmia (Rogers et al. 2011). Less obvious external signs include the tightening of the abdomen, bulging membranes (particularly the branchiostegal membrane near the throat and operculum), and sometimes a prolapsed cloaca (Jarvis and Lowe 2008) (Table 2).

Internal damage from barotrauma that is not obvious unless the fish is dissected and examined, sometime at the tissue level (histologically), includes hemorrhages, organ damage and displacement, swim bladder tears and ruptures, emphysema, and embolisms (Table 2). Internal injuries are important to consider because they may cause mortality or long-term health problems (Hannah et al. 2008b, Pribyl et al. 2011). Causes of mortality include bleeding into the abdominal cavity and vascular gas embolism interfering with cardiovascular function. Damage to the liver and other internal organs, as indicated by hemorrhages, from severe or moderate organ displacement or torsion, as well as damage to the kidney, head kidney or heart, can all lead to longer term health deficits (Hannah et al. 2008b). Tears or ruptures to the swim bladder, either as a partial tear to the outer membrane, the tunica externa, or a full rupture if both layers of the bladder, can result in behavioral issues as the fish has trouble regulating its buoyancy (Rankin et al. 2017). However, Parker et al. (2006) found that Black Rockfish have a good ability to heal following a swim bladder rupture after simulated capture; 77% of the ruptured swim bladders had at least partially healed and were holding gas upon dissection after 21 days in the lab.

Table 2. Barotrauma signs and symptoms observed in rockfishes.

External

Abbreviation	Barotrauma Sign	Description
TA	Tight Abdomen	Abdomen swollen, tight to touch, or distended
BM	Bulging Membrane	Outward bulge in the branchiostegal membrane
ME	Membrane Emphysema	Air spaces or bubbles visible within the branchiostegal membrane and/or pharyngeo-cleithral membrane.
EX	Exophthalmia	Eye protruding outward from the orbit
OE	Ocular Emphysema/Corneal Emphysema	Gas present within the eye or connective tissue surrounding the eye; also called corneal emphysema
EE	Esophageal Eversion/Stomach Eversion	Eversion of esophageal tissue at least 1 cm into the buccal cavity
PC	Prolapsed Clocoa	Everted anal vent

Internal

Abbreviation	Barotrauma Sign	Description
ST	Swim bladder Tear	Swim bladder can be partially ruptured (ruptured tunica external) or fully ruptured indicated as a visible tear in both layers of the bladder. A full tear is also indicated by the swim bladder holding no gas or collapsing under light finger pressure.
OD	Organ Displacement/Torsion	The liver, stomach, intestines and other abdominal organs are pushed towards or into the pharynx.
HE	Internal hemorrhage	Hemorrhages are noted in the literature as unspecified hemorrhages or as hemorrhages in the liver, pericardium or swim bladder and as blood in the peritoneal cavity. All are listed here, using the highest proportion by species and study as HE for the sake of comparison.
IE	Internal embolism	Any embolism or emphysema noted internally upon dissection or histological investigation including the heart ventricle, *rete mirabile*, head kidney, or as an arterial embolism. All are noted here, using the highest proportion as IE for the sake of comparison.
HP	Pericardium Hemorrhage	Blood in the pericardium
HL	Liver Hemorrhage	Blood in the liver or torn liver
BP	Blood in Peritoneal Cavity	Some or severe blood in the peritoneal cavity noted
HVE	Heart Ventricle Emphysema	Histological evidence of gas bubbles visible in the heart ventricle
ERM	Emboli in the Rete Mirabile	Histological evidence of embolism
HKE	Head Kidney Embolism	Histological evidence of emboli in the vessels of the head kidney
AE	Arterial Embolism	Presence of gas embolisms in pericardial chamber and swim bladder

Barotrauma signs and survival rates for inshore rockfish and some shelf rockfish species are summarized below in the species synthesis section and in greater detail in the research document. Survival rates are usually measured over a short period of time (24-48 hours) and have been measured by holding the descended fish in cages (Jarvis and Lowe 2007, Hannah et al. 2008, 2012, 2014), or laboratories, (Pribyl et al. 2012, Rankin et al. 2017) but can be over longer periods using tag-recapture (Hochhalter and Reed 2011) or telemetry (Wegner et al. 2016) studies. As with barotrauma symptoms, survival has been inversely related to depth.

Hannah et al. (2012) measured survival in cages over 48 hours later and showed 100 % survival for Canary, Quillback, Yelloweye, Copper, and China Rockfishes caught between 9-64 m of depth. Black and Blue Rockfishes showed an inverse relationship between capture depth and overall survival with rates of 90% and 78%, respectively. Hannah et al. (2014) compared Canary Rockfish with Yelloweye Rockfish caught at deeper depths (46-174 m) and found a 95% survival across all depths for the Yelloweye Rockfish, although slight declines in survivorship were seen with depth. Canary Rockfish survival declined to only 20% at capture depths greater than 135 m. Fish of both species that died were found to have blood pooling under the pharyngo-cleithral membrane, in the abdominal cavity, and/or the pericardial cavity. A further study found a similar 48 hr survival rate (89%) for Yelloweye Rockfish (Rankin et al. 2017).

A mark-recapture study initiated in Alaska to determine the survival of Yelloweye Rockfish caught between 19 and 74 m, and released at depth using a deep-water release device, estimated survival for the recompressed fish was 0.988 with a 95% confidence interval of 0.478 to 0.999 (Blain and Sutton 2016). Some of these tagged fish were subsequently recaptured 1 and 2 years later and the results indicated that reproduction had not been compromised; recaptured Yelloweye Rockfish females remained reproductively viable even after two recompression events. In another study, acoustically tagged Cowcod, Bocaccio, and Bank Rockfishes returned to depths between 91 – 183 m using recompression devices and tracked in an acoustic array (Wegner et al. 2016) were observed to have a 72% survival for all species combined for over 10 days, and no mortalities for up to 4 months of monitoring; although some fish left the detection array. Bocaccio, the only species from this study found in BC, had a 92% survival rate over a 3 year time period (not including fish that left the array).

Sub-lethal and Behavioral Impairment

Because long-term estimates of survival for rockfishes that have been recompressed are limited, researchers have also assessed behaviour of fishes upon release after being recompressed. The behaviour of nine species after recompression and release were examined by Hannah and Matteson (2007) using video cameras attached to release cages. A composite behavioral score was based on the fish's ability to orient vertically within the cage and while exiting the cage, and if the fish was able to swim and how long this took. The behaviorally impaired rockfish were found to have difficulty maintaining their vertical orientation and were slow to leave the release cage. The effects of depth on behavioral impairment were species-specific, with lower behavioral scores for Black Rockfish, Blue Rockfish, and Yelloweye Rockfish at increased depths. Blue rockfish that were caught at depths of 40-99 m, had the most seriously impaired behaviour of the species studied (Hannah and Matteson 2007).

Behavioral impairment in Yelloweye Rockfish was examined by Rankin et al. (2017) during recompression and after recompression. They found that during the recompression descent, the positively buoyant fish were disoriented and upside down or lying on their sides in the cages. Upon reaching the bottom, those fish captured in shallow water (54-89 m) were immediately oriented upright. By contrast, half of the deep captured (122-199 m) fish remained lying on their sides for approximately one hour. When the cage was opened, the fish caught in shallow water exhibited "vision-dependent" behaviour (defined as fish avoiding an opaque barrier in the cage), while most (75%) of those rockfish caught at depth did not avoid the barrier, exhibiting impaired "vision-dependent" behaviour. The cause of the impaired vision in Yelloweye Rockfish is attributed to the presence of ocular emphysema, which can take up to 48 hours at depth to resolve (Hannah et al. 2012, Rankin et al. 2017).

Rankin et al. (2017) also observed the ability of recompressed Yelloweye Rockfish to maintain neutral buoyancy and upright orientation while swimming. Although all of the fish were able to orient upright, none of the fish could maintain neutral buoyancy. The consequences of negative

buoyancy include energetic costs, difficultly acquiring prey and interacting with conspecifics, increased predation risks as a result of labored or atypical swimming patterns, and general problems with movement (Rankin et al. 2017). At the conclusion experiments (15 or 30 days), the fish were sacrificed and internal barotrauma signs were noted including severe internal bleeding and extensive hemorrhages in the swim bladders. Although most of the swim bladders were partially intact, one was completely ruptured and all others remained damaged. They observed gas between the swim bladder and body wall and within the tunica layer, inflammations, ruptured tunica externas, brown fluid in swim bladders, and a swollen, discoloured *rete*. The findings presented in Rankin et al. (2017) reveal severe and lasting injuries as well as behavioural compromise of recompressed deep-water Yelloweye Rockfish. Black Rockfish held in the lab have demonstrated swim bladder recovery at a rate of 77% over 21 days (Parker et al. 2006) and 50-80% over 31 days (Pribyl et al. 2012), indicating that although swim bladder repair is possible, recovery in some proportion of fish will take an extended amount of time. Pribyl et al. (2012) also note that swim bladder recovery in a laboratory setting might not be representative of fish in the wild because food is available and predators are absent. It is unknown how this injury will affect survival in the wild.

Synthesis of Results by Species in BC

Yellowtail Rockfish

Yellowtail Rockfish appear to be the species least affected by barotrauma as a result of their ability to vent gas from their pharyngo-cleithral membrane (Hannah et al. 2008b, Pribyl et al. 2009). This reduces the signs of barotrauma. Yelloweye rockfish are a mid-water schooling fish that makes large vertical migrations naturally and seems to be better adapted to handle pressure changes.

Bocaccio

Bocaccio have also been observed making high vertical movement changes. They also seem to survive being recompressed well after barotrauma events with a 92% survival rate over a 3 year time period (Jarvis and Lowe 2008, Wegner et al. 2016).

Quillback Rockfish

Quillback Rockfish are a deep-bodied demersal species, not known to make large vertical or horizontal migrations (Hannah and Rankin 2011). It is, therefore, surprising, that they appear to show fewer external barotrauma signs and survive recompression well. Similar to Yellowtail Rockfish, Quillback have been observed venting gas from their branchiostegal membranes, which reduces pressure placed on the esophagus and leads to low incidence of esophageal eversion (Hannah et al. 2008b). Short-term survival (48 hours) was high (Hannah et al. 2012). Long-term survival, behaviour, and sub-lethal studies have not been done on Quillback Rockfish.

Copper and Brown Rockfishes

Closely related to Quillback Rockfish, we might expect similar barotrauma effects and survival for Copper and Brown Rockfishes, which have not been studied in as great of detail. 48-hour survival was high at 100%, although sample sizes were small (Hannah et al. 2012).

Black Rockfish

Black Rockfish are a mid-water species that have been extensively studied. Despite high rates of external and internal barotrauma signs, short term (48 hr) survival was high (90%) (Hannah et al. 2012) and longer term (21 days) survival in the lab was 97% (Parker et al. 2006). Survival has been related to the depth of capture (Hannah et al. 2012).

Blue and Deacon Rockfishes

Blue Rockfish occupy a similar niche to the closely related Black Rockfish. Their survival was lower than Black Rockfish over a 2-day experiment and related to capture depths (Hannah et al. 2012). All work on Blue Rockfish and barotrauma and recompression has been focused on *S. mystinus*. A recent study shows that Blue Rockfish in BC are likely a separate species, the Deacon Rockfish (*S. diaconus*) (Frable et al. 2015). Unpublished research on Deacon Rockfish conducted in Oregon showed that Deacon Rockfish caught above 27 m, re-descended and held for 24 hrs had 100 % survival, but survival dropped to 78% and 71% between 28-36 m and 37-45 m, respectfully. Survival of Deacon Rockfish caught between 46-54 m dropped to only 25%, indicating that deeper caught Deacon Rockfish are quite fragile (personal communication, Polly Rankin, Oregon Department of Fish and Wildlife, Newport, Oregon).

China and Tiger Rockfish

Little work has been done on China and Tiger Rockfishes, however a small sample (3) of China Rockfish showed 100% 48 hour survival (Hannah et al. 2012). Physiological examination of China Rockfish has shown much slower ability to reabsorb gas than Black Rockfish, which is consistent with its benthic, sedentary lifestyle (Parker et al. 2006). Tiger Rockfish, which similarly have a sedentary, benthic lifestyle, but which are typically found deeper than China Rockfish might be expected to have low survival rates. Tiger Rockfish have shown high rates of external barotrauma signs (Hannah and Matteson 2007) but survival has not been studied.

Yelloweye Rockfish

Barotrauma and recompression of Yelloweye Rockfish have been extensively studied (Hannah and Matteson 2007, Hannah et al. 2008a, Hochhalter and Reed 2011, Hannah et al. 2012, Hochhalter 2012, Hannah et al. 2014, Blain and Sutton 2016, Rankin et al. 2017). Short-term (48 hr) survival rates of Yelloweye Rockfish have all been very high (90-100%) with a trend of decreased survival with increased capture depth. A long-term tag-recapture experiment on fish that had been released at depth revealed a high probability of survival, 0.98 over 17 days; however, this study produced wide confidence intervals (0.48-0.99). The capture depth for this study was also relatively shallow, 19-74 m; however, most fish were captured above 55 m (Figure 1 in Hochhalter and Reed 2011). Another interesting finding of this study was that fish under 40 cm in length were not recaptured. This leads to questions about increased mortality from barotrauma or increased risk of predation for smaller rockfish by Lingcod (Beaudreau and Essington 2007) or other predators. Yelloweye Rockfish occupy deeper depths than most other inshore rockfishes (Table 2). Depth of capture is therefore a concern. Although short-term (48 hr) survival of Yelloweye caught between 135-174 m of depth was still relatively high (90%) (Hannah et al. 2014), work by Rankin et al. (2017) on the extensive internal damage of Yelloweye Rockfish caught between 140-150 m cannot be ignored. They conclude "the findings of these two studies, which reveal severe and lasting injuries, as well as behavioral compromise of recompressed deep-water Yelloweye Rockfish reinforce the importance of avoiding fishing contact with deep-dwelling Yelloweye Rockfish and maintaining spatially-managed rockfish conservation area closed to fishing."

Canary Rockfish

Canary Rockfish have also been extensively studied (Hannah and Matteson 2007, Hannah et al. 2008a, Hannah et al. 2008b, Pribyl et al. 2011, Hannah et al. 2012, 2014). Although Canary Rockfish show high 48-hour survival in shallow water (Hannah et al. 2012), survival is greatly reduced with depth of capture below 75 m and was as low as 20% at depths of 135-174 m (Hannah et al. 2014). Hannah et al. (2014) conclude that there may be a critical capture depth

for some rockfish species at which post-recompression survival decreases rapidly, as it did for Canary Rockfish.

Barotrauma Mitigation

There have been various methods developed to mitigate the effects of barotrauma on rockfish. One approach is to 'vent' the fish, by inserting a hypodermic needle directly into the swim bladder to remove the trapped gas (Theberge and Parker 2006). This method relies heavily on the skill and experience of the person venting the fish, because improper technique can cause extensive damage to the fish. As a result of injuries and infections in the fish's body cavity that can be caused by venting, or "fizzing" rockfishes and Washington, California and Alaska all recommend that anglers not vent rockfish (e.g., Washington Department of Fish and Wildlife). There is also potential for injury to the person venting a rockfish because of the large, venomous spines in some species of rockfish (Theberge and Parker 2006).

Another method to mitigate barotrauma in rockfish is to use recompression devices to force the return of the affected fish to depth. A variety of devices have been designed to recompress a broad diversity of fishes. Commercially available fish descending devices range from simple mechanical devices that clip to a line or fishing rod to more technologically advanced depth/pressure release devices to a weighted milk crate on a line (Theberge and Parker 2006, Chen 2012, Hudson 2015). Some devices take practice in order to be able to use them efficiently. For example, there is the potential to cause further injury to the fish if using hooks or crates to descend, and in high current, crates may drift reducing the certainty of release depth (California Sea Grant 2008). It is unknown how effectively recreational fishers use descending devices (Chen 2012). A recent study showed that recreational fishers preferred using the lower jaw clamp with pressure sensor release, with the weighted crate being the second preference. These two methods also had the highest proportion of successful descents whereas other devices didn't always release the fish at depth (Lyall Bellquist, Western Groundfish Conference, Seaside California, February 13-16, 2018). Pressure sensor release devices require regular maintenance and recalibration in order function properly (John Harms, Western Groundfish Conference, Seaside California, February 13-16, 2018). The ideal depth that a fish should be returned to is also unknown. Some agencies recommend at least ½ the capture depth, or 60 feet (18 m), or return to the capture depth.

When considering the use of recompression devices for recreational anglers, there are other factors that can influence the success of the devices, such as how the rockfish was initially caught. For example, location of the hook in a captured fish has been found to have a statistically significant impact on survival – despite whether or not recompression was used (Roach et al. 2011). Hooks can cause various types of injuries to fish depending on the anatomical location of the hook on the fish – for example, post-capture mortality was higher if the fish had ingested the hook, as opposed to being hooked in the lip or mouth.

The time a fish spent at the surface has been found to be the most significant predictor of short-term survival of rockfish that had been recompressed (Jarvis and Lowe 2008). Parker *et al.* (2006) recommends rapid recompression, and suggests that minimal time and handling at the surface will reduce the impacts of physiological stress on the fish. Stress involved in the forced ascent and handling cause increases in lactic acid and tissue CO_2, which lowers pH and the solubility of blood gases, which can contribute to embolisms. Reduced time on the surface will also reduce the negative impacts of low pressure, thermal stress, and asphyxia and improve post-recompression survival. Scientific studies on barotrauma control for surface time; however, the amount of time it takes recreational fishers to recompress rockfish is unknown and is likely dependent on the device used and the experience of the fisher. Washington, Oregon, California,

and Alaska have all developed best practices outreach material on how fishers should recompress rockfishes.

The use of Descending Devices in Recreational Fishery Management of Rockfishes in the United States

Pacific Fishery Management Council (PFMC)

The PFMC has developed discard mortality rates for rockfishes released at the surface as well as fish released at depth with a descending device (Pacific Fishery Management Council 2012). Mortality rates have been developed for Canary and Yelloweye Rockfishes, which account for variation between species and differences in sample size (Pacific Fishery Management Council 2012). The PFMC adopted buffers for uncertainty based on the upper 90% confidence interval estimate of the short-term mortality for use in management in 2014 (Benaka et al. 2014). The proxy species used were: 19-55 m: Canary, Yelloweye, Copper, and Quillback Rockfishes; 56-91 m: Yelloweye Rockfish; >91 m: Cowcod (*S. levis*), Bocaccio, Bank (*S. rufus*) and Sunset (*S. crocotulus*) Rockfishes. The mortality rates with 90% confidence intervals for Yelloweye and caught above 30 m, between 30-50 m and below 50 m are 21%, 37% and 45%, respectively and 21%, 27% and 45% for Canary Rockfish. These mortality estimates were made before the publication of the two important studies described above that showed that Canary Rockfish mortality declines to 80% below 135 m (Hannah et al. 2014) and the sub-lethal and behavioural effects of barotrauma on deep-dwelling Yelloweye Rockfish may impact long-term survival (Rankin et al. 2017). In addition, these mortality rates were developed with the assumption that the proxy species used to increase the sample sizes in each depth bin are appropriate and have similar life history characteristics, and react similarly to rapid depressurization. This assumption is counter to much of the evidence presented in this literature review that points to high variability among species (Hannah and Matteson 2007, Jarvis and Lowe 2008, Pribyl et al. 2009, Pribyl et al. 2011), particularly species within different guilds such as demersal Yelloweye Rockfish and the more mid-water Bocaccio Rockfish (Love et al. 2002).

California

The California Department of Fish and Wildlife (CDFW) use the mortality estimates adopted by the PFMC, as well as depth-stratified mortality rates for rockfishes that are released at the surface, in their management of recreational fisheries (Pacific Fishery Management Council 2013). Applying these mortality estimates in management requires the following information: the disposition of the discard (was the fish discarded at the surface or with a descending device); the species (mortality rates associated with descending device use are species-specific); and the depth of capture to ascribe catch to a depth bin. In addition, data are stratified by month, district (six districts with different disposition rates), depth (10-fathom depth bins), and fishing mode (commercial passenger fishing vessels (party boats) or private/rental boats). The California Recreational Fisheries Survey (CRFS) samplers collect information about recreational fishing in a creel survey, enter data into a database, and apply estimation methods. To account for the use of descending devices CRFS samplers were trained to collect additional information including use of descending devices and the depth fished; the database was updated with additional fields and codes to account for disposition; and the estimation program was updated to run the algorithms to account for the use of descending devices. CDFW has also used data collected in the creel surveys on the use of descending devices to direct outreach amongst low-use areas and has collaborated with fishing clubs to generate support for descending devices. At this time the use of descending devices remains voluntary (Burdock 2016).

Oregon

The use of descending devices in Oregon has recently been made mandatory. The regulation is as follows:

"Any vessel fishing for, or possessing bottomfish, including flatfish species or Pacific Halibut in the ocean must have a functional descending device onboard, and use when releasing any rockfish outside 30 fathoms (55 m). Functional descending device means one that is ready to be used."

Mortality rates for Yelloweye Rockfish by depth bin for fish released at the surface or by descending device developed by the PFMC are used. Advice received by anglers in 2016 supported making descending devices mandatory rather than shortening the fishing season (Oregon Department of Fish and Wildlife 2016).

Washington

In response to Yelloweye Rockfish and Bocaccio being listed under the Endangered Species Act in 2010, the Washington Department of Fish and Wildlife (WDFW) accelerated recovery planning already in progress, closed many commercial fisheries, prohibited the recreational retention of all rockfish species, prohibited fishing for bottomfish in waters deeper than 36.6 m (120 feet) in Puget Sound, and promote the descent of rockfishes. Although retention of rockfish is illegal, bycatch mortality still occurs and is managed to an annual target of 5,000 pounds (2268 kg) by all fisheries. Phone and dockside creel interviews collect information on catch and bycatch by species, management area, and target type (salmon, bottomfish, halibut, and other). Sampled catch and bycatch composition is applied to effort levels from phone surveys to produce interaction estimates of catch (Lowry 2016). In 2013, a question about the release of rockfish was added to the angler interview and in 2014, a question on the use of descending devices was also added (Wargo 2016). In order to estimate mortality of released rockfish, the WDFW uses information on the proportion of each species found in water less than 36.6 m from fishery-independent surveys (ROV, trawl, drop camera, and dive surveys). They also apply the PFMC mortality estimates for species caught shallower than 36.6 m and released at the surface. Fish caught deeper than 36.6 m are assumed to have 100% mortality. WDFW has also undertaken outreach and education aimed at recreational anglers to increase awareness of barotrauma and its impacts, describe the benefit of descending rockfish back to depth, and present the best techniques and tools to descend fishes. It includes materials and information on rockfish species identification and web, poster, and brochure information on "sending that rockfish down' (WDFW 2013, Wargo 2016). Despite considerable outreach, overall use of descending devices is low and is estimated to be between 5% and 7%, depending on area and species (Lowry 2016, Wargo 2016). In response to evidence that voluntary use of descenders was at levels too low to be meaningful to conservation efforts, the possession of a functional descending device for all recreational anglers targeting bottomfish was made mandatory in Washington in 2017. Due to the mandatory use as well as outreach by WDFW, reported use of descenders has climbed to 20% in 2017 (Dayv Lowry, Washington Department of Fish and Wildlife, Olympia, Washington, Pers. Com.).

Alaska

Information on the proper use of various descending devices is given on the Alaska Department of Fish and Game (ADFG) website; however, the use of descending devices is a voluntary guideline and catch-and-release fishing for rockfishes is discouraged. The ADFG has been conducting research to measure the effectiveness of devices that allow rockfish to be released at depth. The ADFG states that the first conservation tool for rockfish is prevention. They recommend avoiding catching unwanted rockfishes while targeting Halibut and Lingcod by

keeping jigs and bait 3-4.5 m (10-15 feet) off the bottom and avoiding rockfish habitats of boulders, ridges, and pinnacles. Similar to the recommended approach in BC, ADFG recommends moving to a different fishing spot when rockfish are being caught unintentionally. Other recommendation to prevent rockfish catch are to target other species first, to avoid excessive rockfish harvest, and to use release-friendly tackle such as circle-hooks. The second conservation tool listed is the use of descending devices. When using descending devices, anglers are encouraged to send the fish back down as quickly as possible to the depth of capture or 45 m (150 feet). In some management areas, anglers may be required to retain the first one or two non-pelagic rockfishes caught.

Knowledge Gaps and Uncertainty

Scientific Uncertainty

Although the recompression of rockfishes through the use of descending devices has the potential to reduce the mortality of released rockfish, several important knowledge gaps remain, particularly for species in BC. Limited information based on very small sample sizes exists for Copper, Brown, China, and Tiger Rockfishes, as well as many shelf species, regarding the effects of rapid recompression. Even less information on survival after recompression exists, especially for the depth and temperature ranges relevant to BC. There is little information on the newly described Deacon Rockfish, although it is closely related to Blue Rockfish and may behave in a similar fashion. Information regarding long-term survival is scarce, even for species that have been studied extensively, such as Black, Canary, and Yelloweye Rockfishes. The critical depth at which survival rates rapidly decrease is unknown for most species. Canary Rockfish survival rates dropped from 80% to 20% between 75 m and 135 m. If this depth were to be known, a management regulation could be put into place prohibiting fishing below a certain depth. However, this critical depth likely varies by species because Yelloweye Rockfish survival did not exhibit as much of a reduction in survival across the same depths (Hannah et al. 2014). Recreational fishing with hook and line for all species of bottomfish is prohibited by the WDFW below 36.6 m in Puget Sound, WA in an effort to conservatively address this uncertainty about species-specific rockfish mortality.

Rankin et al. (2017) showed that lasting and severe internal damage to swim bladders and other organs persisted after 30 days post-recompression in deep-dwelling Yelloweye Rockfish and Pribyl et al. (2012) found that the primary problem Black Rockfish experience following recompression is negative buoyancy from a ruptured swim bladder. Understanding the population-level consequences of behavioral and sub-lethal effects of barotrauma in recompressed rockfish across a depth gradient would greatly help in the assessment of the value of descending devices in rockfish conservation and management. Clearly some energetic and behavioral costs exist, such as their ability to move effectively, find refuge and prey, and avoid predators upon release (Rankin et al. 2017). The effect of these costs to rockfish populations is, however, unknown.

Predation risk that recompressed fish experience is also likely not equal across species, or across body sizes within a species. Tagged Yelloweye Rockfish under 40 cm had lower survival rates and may have had greater predation pressure post-recompression (Hochhalter and Reed 2011). More tag-recapture or acoustic tagging studies are needed on rockfish species to better understand these risks (Pribyl et al. 2012).

The survival rates of recompressed rockfish that are found in the literature are from scientific studies, and survival rates when fish are recompressed by recreational fishers are likely to be different. The difference in stress, injury, and the resulting mortality rate will vary depending on the experience level of the angler handling the fish and their regard for the survival of fish

(Pacific Fishery Management Council 2012). Handling time, hooking injuries, temperature, and time on deck are all factors known to affect survival, which are difficult to manage for in a recreational fishing context. No research exists on the most successful descenders to use or the optimal depth to which a fish should be returned. There is also a lack of information about survival rates when fish are caught in fisheries other than hook and line fisheries, such as in traps or trawls; however, mortality on inshore rockfishes from traps and trawls is much lower than it is from hook and line fisheries. Additional injuries associated with these fisheries might affect survival after recompression. Another information gap concerns the effect of multiple recaptures on the survival and health of a fish.

Information Required for Management

How to best incorporate descending devices into recreational management is also yet to be determined. In order to develop appropriate mortality rates for the use in discounting catch, information on capture depth by species would be required. Currently, we have no information on the capture depth from the recreational fishery and the ability of anglers to correctly identify rockfish species remains uncertain. Catch monitoring programs (Creel survey and iRec) would need to be expanded to collect data on the identity of rockfish species released by fishers, the depth of capture, and the proportion of fishers using descending devices.

The PFMC has made an effort to determine mortality rates for recompressed Yelloweye and Canary Rockfishes; however, estimates do not take into account more recent research results on short- and long-term mortality for these species when caught in deep water (Hannah et al. 2014, Rankin et al. 2017) and rely on data from proxy species that may not be appropriate.

Enforcement of the use of descenders may realistically be limited to the mandatory possession of a descender, as it is in Oregon. It is unlikely that the proper use of a device can be enforced. Compliance with existing rockfish conservation measures and knowledge of recreational management regulations has been shown to be low (Lancaster et al. 2015, Haggarty et al. 2016, Lancaster et al. 2017). Therefore enforcement, outreach and education programs to teach recreational fishers how to identify rockfishes and to properly handle and return fish to depth them would be imperative to ensure successful mitigation of rockfish mortality.

Conclusions

Rockfish species show resiliency in their ability to recover from barotrauma and to survive after recompression. However, the effects of barotrauma and the survival rates are complex in this diverse genus of fishes and a number of uncertainties remain. Although recompression increases the survival rates of discarded fish that would otherwise be unable to descend, and therefore remain at risk of predation by birds and mammals, accounting for uncertainties in short- and long-term mortality of descended rockfish complicates the calculation of mortality estimates. Given uncertainty about the long-term effects of barotrauma at the population level, maintaining effective rockfish conservation areas closed to fishing is a critical component to rockfish conservation and rebuilding plans. Incorporating the voluntary or mandatory use of descending devices in the management of recreational rockfish fisheries will require careful consideration because considerable uncertainty about their effectiveness to mitigate rockfish mortality remains.

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